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This grant has funded our research during the past three years on the geophysical structure of the Baikal Rift. The results of our analyses are briefly summarized below, and contained in full in the Ph.D. thesis of Dr. Carolyn Ruppel, who successfully defended her dissertation on November 18, 1991.

OVERVIEW

Active deformation at and near the surface of continents represents a manifestation of processes operating at depth and provides constraints on the underlying thermal, mechanical, and dynamic structure of the continental lithosphere. The three major studies undertaken with NASA support of this research grant focus on characterizing various aspects of continental thermal structure in the Baikal Rift zone (BRZ), with some comparisons to other rift and continental swell features, such as the East African Rift and the Rio Grande Rift. For each study, our approach involved incorporating both geological and geophysical data to understand the first-order problem of how the crust and mantle lithosphere respond thermally and mechanically to deformation.

THE BAIKAL RIFT ZONE: TECTONICS, SHALLOW COMPENSATION, AND CONSTRAINTS ON DRIVING MECHANISM FOR RIFTING

The Baikal Rift Zone (BRZ) of eastern Siberia represents the cold, discrete endmember in the class of active intracontinental rift systems, and a variety of geological and geophysical data constrain its thermal and mechanical structure at depth and the mode of compensation for the short-wavelength (<1000 km wavelength) topography. The onset of rifting in a narrow, sinistral zone at the edge of the Siberian platform and Aldan shield was marked by a sudden change in the character of sedimentation and tectonism at approximately 4 Ma, and lateral variations in the lithosphere's response to rifting led to the evolution of four distinct tectonic provinces: (1) The Sayan region, west of Lake Baikal's southernmost tip and close to the 1000 km long Main Sayan fault; (2) The axial rift zone, which is concentrated along the Paleozoic suture zone and consists of the three laterally-heterogeneous and diachronously-evolving Lake Baikal basins; (3) The Barguzin accommodation zone, which links deformation in the South and Central Basins of the axial zone to left-lateral motions north and east of the lake; and (4) The Udokan shear zone, which extends nearly due east from the northernmost tip of Lake Baikal and includes five rift basins arranged in a loose en echelon pattern.

Topography, seismic, heat flow, gravity, and magnetic data also indicate significant lateral heterogeneity along the BRZ and quantitatively constrain temperatures at depth. The topographic dome over the BRZ reaches a relative amplitude of approximately 400 m, and the axis of the rift has well-developed flanks and a basin whose water depth and sediment thickness respectively exceed 1600 m and 7 km in places. The BRZ is among the most seismically-active regions of the Asian interior, and the Central and South Basins in the axial zone and the Barguzin basin in the accommodation zone are sites of active coseismic deformation, in sharp contrast to the nearly aseismic North Basin of Lake Baikal. Refraction data indicate that P-wave velocities along the axis of the BRZ do not differ from those beneath the platform and folded regions by more than the estimated uncertainty in the data, and no firm evidence exists for thinning of the crust beneath most of the axial zone of the BRZ. Heat flow in the BRZ vary widely between a background value of 30-45 mW/m^2

in the undisturbed region to the west (within the range for stable continental lithosphere) and an average of 60-75 mW/m^2 or greater within Lake Baikal, the site of most of the measurements. The presence of a thick sedimentary column in the lake should cause a reduction in heat flow due to thermal blanketing effects, and the observation of high heat flow there is thus interpreted as a consequence of hydrothermal circulation through fault zones. Bouguer gravity data over the BRZ are dominated by the short-wavelength low associated with sedimentary fill in Lake Baikal, but longer-wavelength features can be explained by regional compensation via flexural support of the topographic load by an elastic plate with rigidity 7×10^{22} to 6×10^{23} Nm. Spectral analysis of the gravity data yields only scant evidence for dynamic compensation at the longest wavelengths and for thinning of the elastic plate towards the axis of the rift zone.

We therefore conclude, based on the lack of a heat flow anomaly, the normal seismic velocities, the appreciable 30-40-km elastic plate thickness, and the small volume of volcanics that the data do not support a thermal mechanism driving extension at Baikal. Passive rifting, perhaps related to stresses transmitted across Asia from the Himalayan orogeny or some other source of intraplate stress, is capable of explaining the main features in the data we analyzed.

STRIKE-SLIP FAULTING AND THE EVOLUTION OF THE BAIKAL RIFT ZONE

Analysis of Landsat photos, measurement of observed fault offsets, and synthesis of data on the rift's morphology, age, thickness of basin sediments, and amount of extension show that much of the opening along the axis of the BRZ may be the result of displacements along large-scale left-lateral strike-slip faults and of the consequent development of pull-apart basins. The predominance of strike-slip faulting over normal faulting has not previously been recognized in any presently existing intracontinental rift system and implies that the future evolution of the BRZ may follow the pattern of the strike-slip Dead Sea rift system.

Strike-slip displacements in the BRZ are interpreted both as the cause of the discrete, brittle, and avolcanic nature of the rift and as an effect of "passive" plate-boundary forces that drive internal deformation of the Asian continent thousands of kilometers from the Himalayan collisional front. Published "passive" models which predict strike-slip faulting, but not extension, near the site of the BRZ are consistent with the interpretation presented here. Furthermore, the geophysical and geological data are not consistent with a more "active" thermal mechanism for rifting; this conclusion is based on: (1) the paucity of rift-related volcanic rocks, (2) the thick elastic plate required by the gravity data, (3) the absence of a well-defined heat flow anomaly, (4) observations of primarily cataclastic, not ductile, deformation at the surface, (5) significant lateral variations in crustal thickness (not expected if the lower crust is ductile enough to flow), (6) the presence of earthquakes to deep crustal levels, (7) high seismicity, and (8) no pronounced reduction in P-wave velocities beneath the rift's axis.

THERMAL AND DYNAMIC SUPPORT FOR CONTINENTAL SWELLS

Continental swells occur in both midplate and extensional settings and serve as the focal point of our study on the thermal, mechanical, and dynamic processes occurring at lithospheric or sub-lithospheric depths beneath the continents. The analysis of continental swells in two tectonic settings—extensional (rifts) and midplate (hotspots)—highlights important similarities and differences both among swells and between the continental and oceanic swells. One of the most important questions is whether long-wavelength continental swells are compensated primarily by buoyancy forces related to thermal expansion of the lithosphere (thermal compensation) or by those due to the presence of hot upwelling material in large or small-scale convective cells (dynamic compensation). We tested the hypothesis that continental swells are thermally supported using a linear programming inversion technique to constrain the thermal structure of the lithosphere beneath these features. The principal constraints in the linear programming inversion are the height of any long-wavelength topographic swell, the surface heat flow, the magnitude of the geoid anomaly, and the thickness of the elastic plate supporting shorter wavelength bathymetry.

For the Baikal and Rio Grande Rifts, their location at the edge of other major tectonic features (the Sayan Mountains and Colorado Plateau, respectively), makes it more difficult to distinguish the existence of a swell, but we conclude that in both cases doming is small in amplitude. For these two rifts, the linear programming inversion demonstrates that the geophysical data can be explained by reheating of the conductively cooling lithosphere using static kernels to relate thermal anomalies to topography and geoid. For the East African Rift system, the data are not consistent with a passive thermal mechanism.

Inversions for the thermal structure beneath two "hotspot swells," the Darfur and Hoggar domes, produce results which do not closely constrain lithospheric geotherms, and, in the case of the Darfur dome, do not imply significant heating of the lithosphere above a "normal" continental gradient.

PUBLICATIONS

In addition to publishing this material in her thesis, Dr. Ruppel is in the process of converting these three studies from thesis chapters to journal articles. The first study on the shallow compensation of the Baikal Rift is intended for submittal to the *Journal of Geophysical Research* in January. The second chapter on the role of strike-slip faulting in the opening of the rift will be submitted to *Geology* this December. The third chapter on the linear programming inversion for deep thermal structure of rifts will be submitted to *Geophysical Journal* in early spring.